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Shaked et al.

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(54) **SYSTEM AND METHOD FOR FREQUENCY REUSE FOR WIRELESS POINT-TO-POINT BACKHAUL**

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(51) **Int. Cl.**

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H04B 1/12	(2006.01)
H04B 1/18	(2006.01)

(52) **U.S. Cl.**

CPC ***H04B 1/126*** (2013.01)

(58) **Field of Classification Search**

CPC H04B 1/12; H04B 1/123; H04B 1/126
USPC 455/276.1, 278.1
See application file for complete search history.

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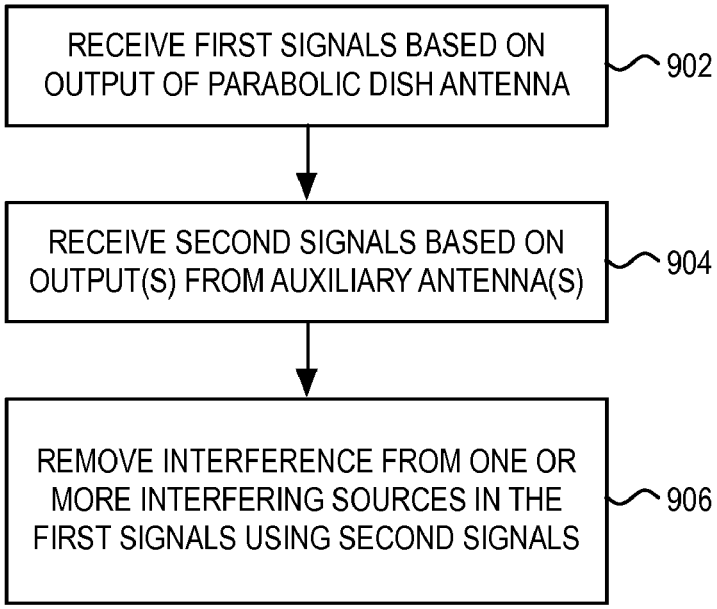
(57) **ABSTRACT**

A system and method for frequency reuse for wireless point-to-point backhaul. Frequency reuse is enabled through the cancellation of interfering signals generated by interference sources. In one embodiment, a conventional dish antenna is complemented with one or more additional auxiliary antennas (e.g., isotropic). The one or more additional auxiliary antennas enable cancellation of interfering signals whose direction of arrival (DOA) is off the dish antenna's bore-sight.

20 Claims, 9 Drawing Sheets



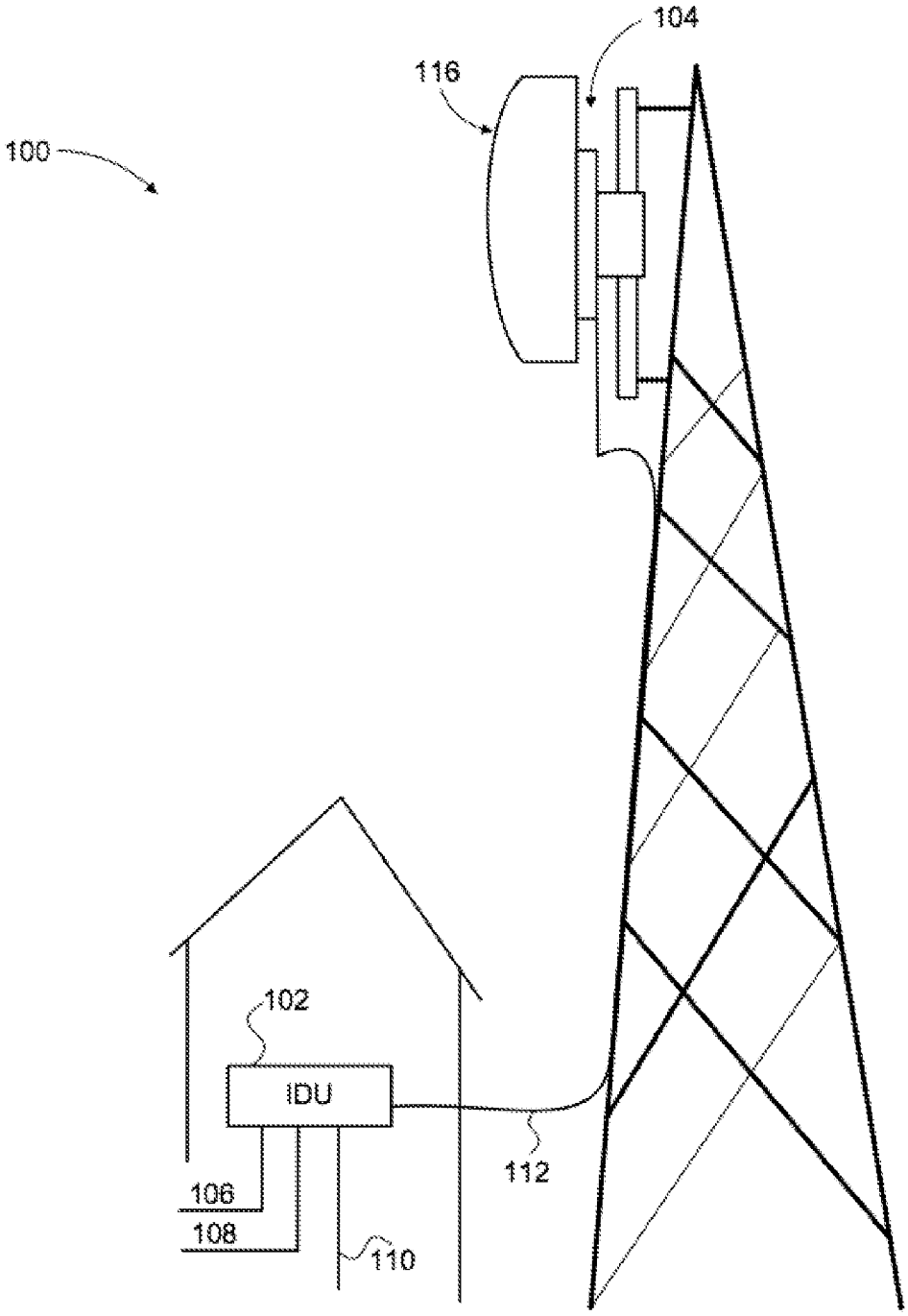


FIG. 1

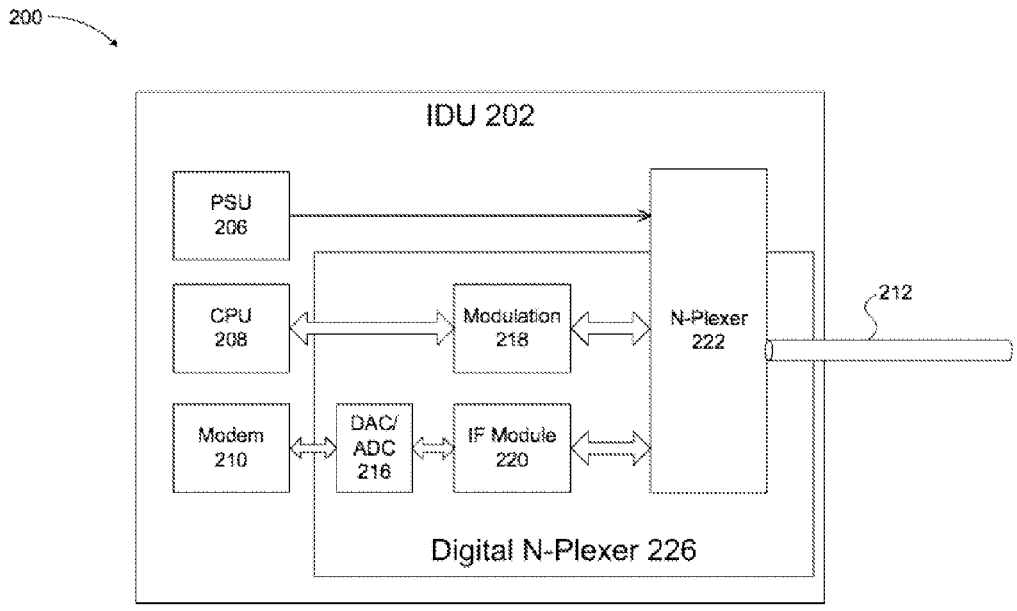

200
IDU 202
PSU 206
CPU 208
Modulation 218
N-Plexer 222
212
Modem 210
DAC/ ADC 216
IF Module 220
Digital N-Plexer 226

FIG. 2A

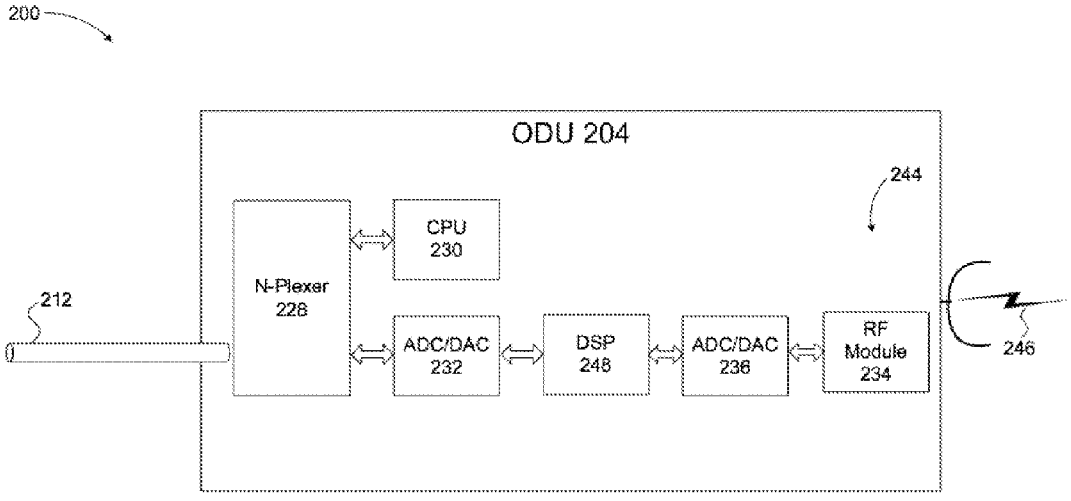

200
ODU 204
244
CPU 230
N-Plexer 228
212
ADC/DAC 232
DSP 248
ADC/DAC 236
RF Module 234
246

FIG. 2B

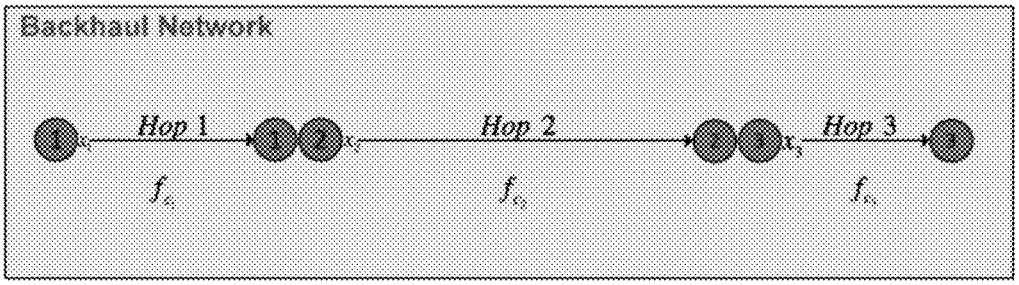


FIG. 3

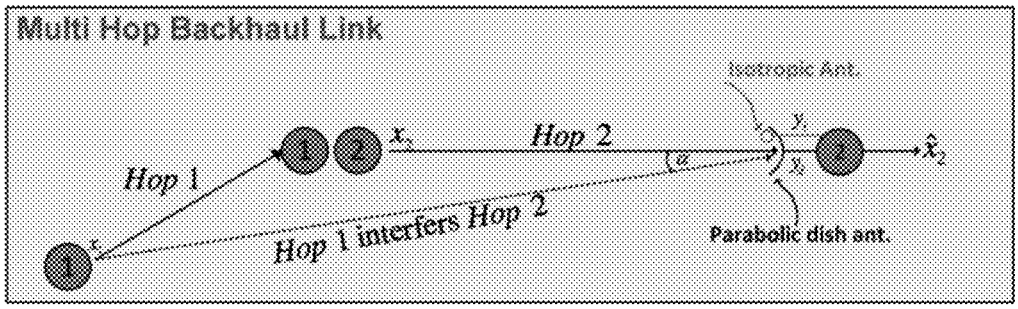

Multi Hop Backhaul Link
Isotropic Ant.
Hop 1
Hop 2
Hop 1 interfers Hop 2
Parabolic dish ant.

FIG. 4

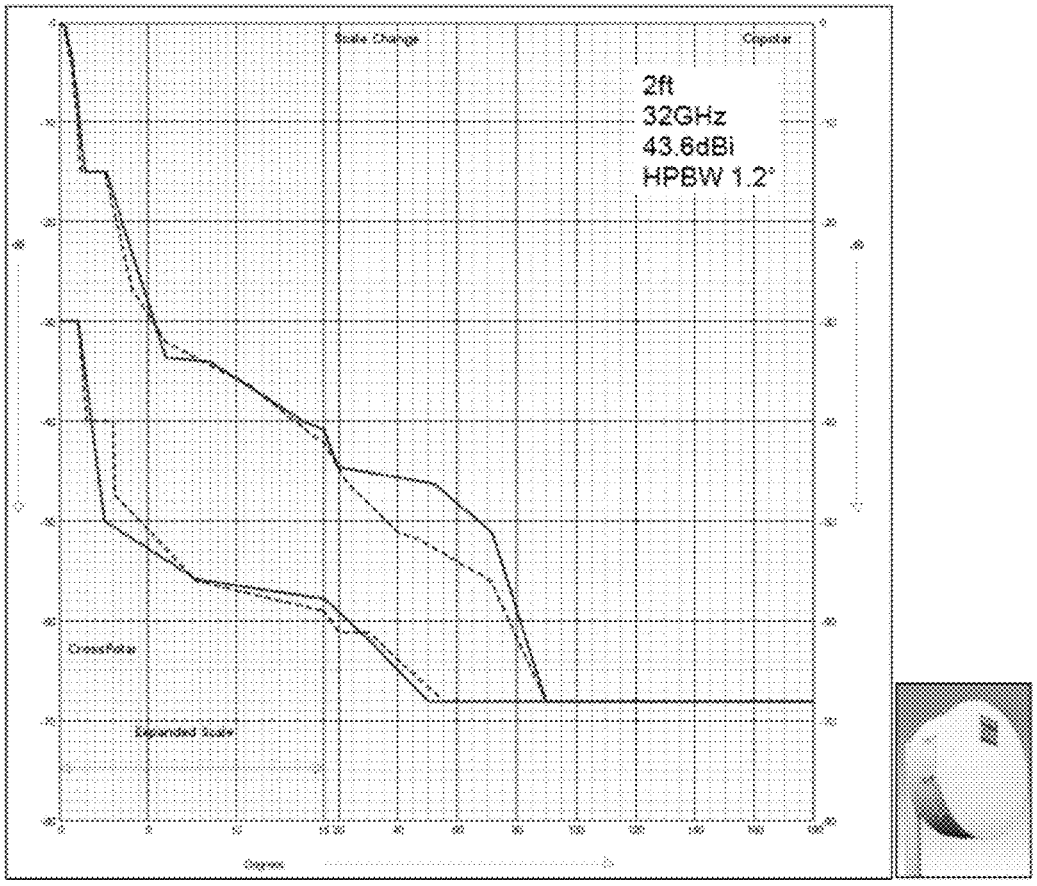


FIG. 5

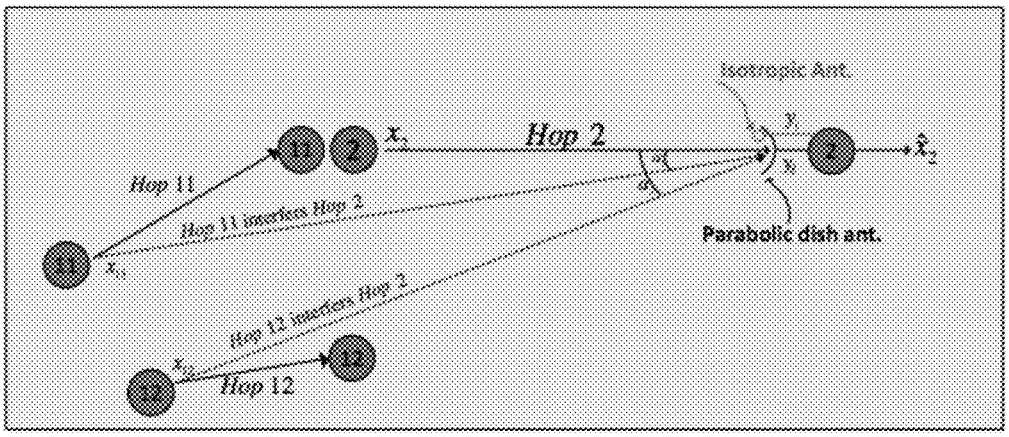

Isotropic Ant.
Hop 2
Hop 11
Hop 11 interfers Hop 2
Parabolic dish ant.
Hop 12 interfers Hop 2
Hop 12

FIG. 6

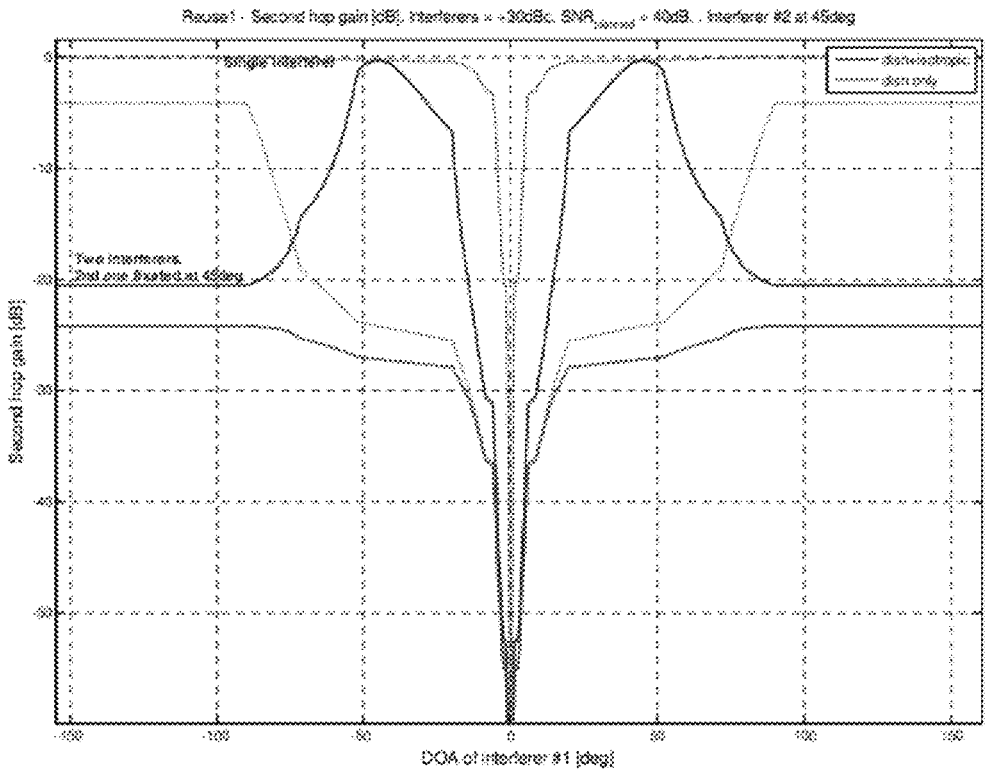


FIG. 7

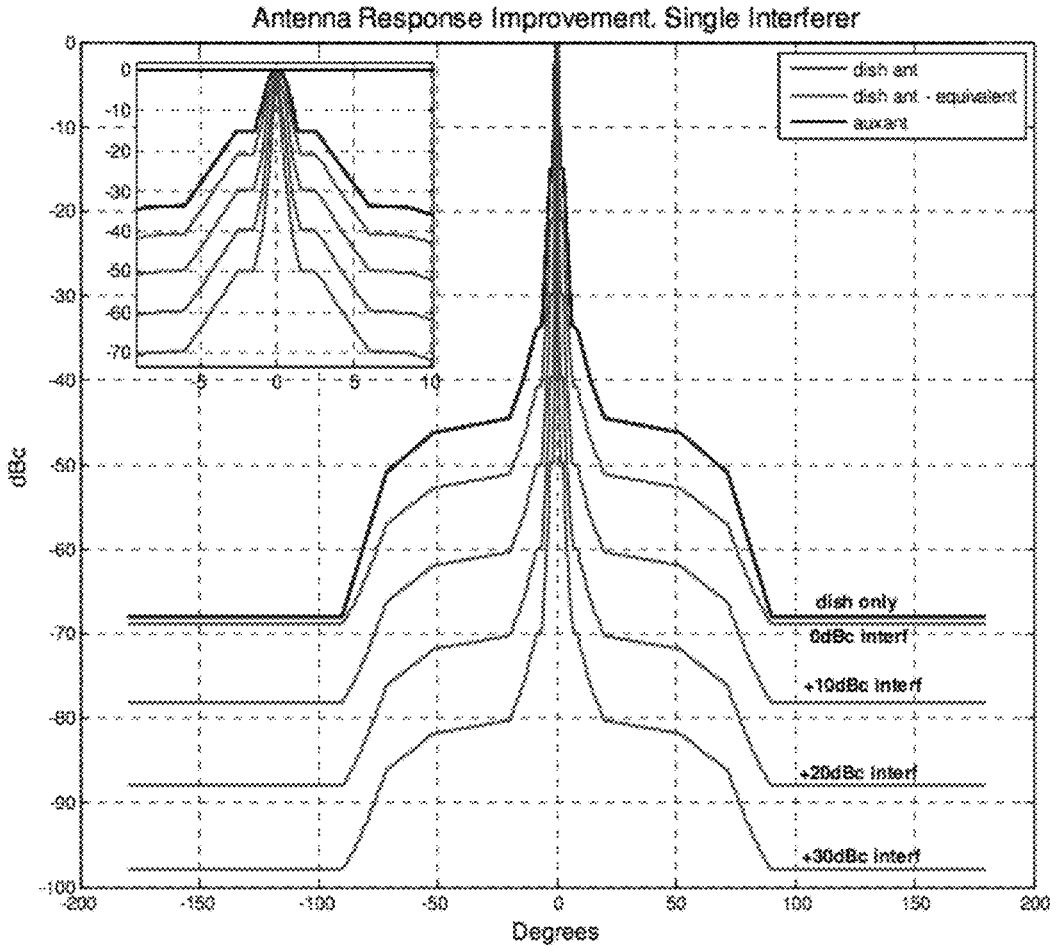

Antenna Response Improvement. Single Interferer
dish ant
dish ant - equivalent
aux ant
dish only
0dBc interf
+10dBc interf
+20dBc interf
+30dBc interf
dBc
Degrees

FIG. 8

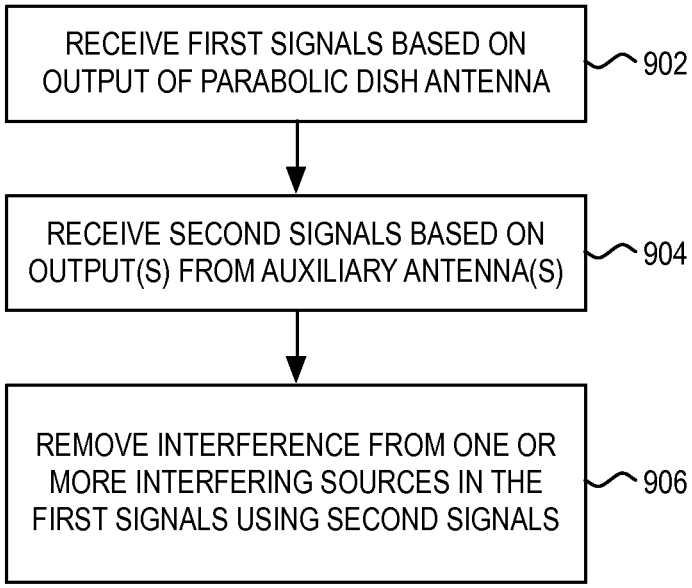

RECEIVE FIRST SIGNALS BASED ON OUTPUT OF PARABOLIC DISH ANTENNA
902
RECEIVE SECOND SIGNALS BASED ON OUTPUT(S) FROM AUXILIARY ANTENNA(S)
904
REMOVE INTERFERENCE FROM ONE OR MORE INTERFERING SOURCES IN THE FIRST SIGNALS USING SECOND SIGNALS
906

FIG. 9

SYSTEM AND METHOD FOR FREQUENCY REUSE FOR WIRELESS POINT-TO-POINT BACKHAUL

This application claims the benefit of and priority to provisional application No. 61/978,376, filed Apr. 11, 2014, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

The present disclosure relates generally to microwave backhaul architecture and, more particularly, to a system and method for frequency reuse for wireless point-to-point backhaul.

2. Introduction

Conventional microwave backhaul architectures are generally implemented as either a split outdoor unit (split ODU) configuration or an all outdoor unit (all ODU) configuration. Conventional split ODU configurations are generally comprised of both an indoor unit (IDU) and an outdoor unit (ODU), where the IDU and the ODU are connected over a single channel coaxial interconnect. The IDU in a conventional split ODU configuration typically includes a modem, a digital-to-analog converter and a baseband-to-intermediate frequency converter.

Mobile backhaul providers are experiencing a growing demand for increased capacity as well as a shift from voice services to data services. These factors are driving mobile backhaul networks towards high capacity IP/Ethernet connections. Additionally, the transition to 4G and LTE networks is also driving the need for higher capacity, and moving more packet traffic onto mobile backhaul networks.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to describe the manner in which the above-recited and other advantages and features can be obtained, a more particular description will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments and are not therefore to be considered limiting of its scope, the disclosure describes and explains with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates a block diagram of a microwave backhaul system according to an exemplary embodiment.

FIG. **2**A illustrates a high-level block diagram of an IDU for implementation within a microwave backhaul system according to an exemplary embodiment.

FIG. **2**B illustrates a high-level block diagram of an ODU for implementation within a microwave backhaul system according to an exemplary embodiment.

FIG. **3** illustrates an example backhaul scenario of a straight-line, multi-hop backhaul link.

FIG. **4** illustrates an example multi-hop backhaul link.

FIG. **5** illustrates an example of a directional dish antenna.

FIG. **6** illustrates an example backhaul link with two interferers.

FIG. **7** illustrates the performance in the example presence of two interferers.

FIG. **8** illustrates an example of antenna response improvement.

FIG. **9** illustrates a flowchart of an example process.

DETAILED DESCRIPTION

Various embodiments are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the present disclosure.

It is recognized that the microwave backhaul world is growing due to increased bandwidth demands. FIG. **1** illustrates a block diagram of an example microwave backhaul system **100** that includes IDU **102** and ODU **104**. Microwave, as used throughout this disclosure, refers to both terrestrial point-to-point (PtP) radio communications, as well as point-to-multipoint communications, and can include both wired and/or wireless communications.

Microwave backhaul system **100** initiates communication by accessing an information source, which can comprise, for example, audio data **106**, video data **108**, or any other data capable of being transmitted over an Internet Protocol (IP)/Ethernet connection **110**. To facilitate this communication, IDU **102** can be coupled to a core network. In particular, IDU **102** can be configured to acquire one or more sequences of digital data (e.g., audio data **106**, video data **108**, data transmitted over IP/Ethernet connection **110**, or the like) from the core network. IDU **102** can also be configured to support several additional services, such as Ethernet, time-division multiplexing (TDM), and control data that is aggregated over a radio link.

IDU **102** can be implemented at a location that is substantially removed from ODU **104**, such as at a location at ground level. For example, IDU **102** can be positioned inside of a home or an office building, or other structure. Conversely, ODU **104** can be implemented at a substantially elevated location, such as on top of a pole, on top of an antenna tower, on top of a building, or other mounted location. In some embodiments, IDU **102** and ODU **104** can be separated by a significant distance (e.g., up to approximately 300 meters). In general, IDU **102** includes a modem assembly, while ODU **104** includes at least some RF functionalities as well as corresponding digital capabilities.

IDU **102** and ODU **104** can be connected via communication pathway **112**, which can be configured such that data can be transmitted between IDU **102** and ODU **104**. In various examples, communication pathway **112** can comprise a twisted pair Ethernet cable, a fiber optic cable, a coaxial cable, an intermediate frequency (IF) cable, or any other cable suitable for IDU-ODU communication. Therefore, depending on a chosen communication medium, communication pathway **112** can facilitate transmission of an analog signal or a digital signal between IDU **102** and ODU **104**. In some embodiments, communication pathway **112** can be a wireless communication channel.

Antenna **116** can be coupled to ODU **104**, and can be positioned close to ODU **104**. Therefore, microwave backhaul system **100** can be implemented such that data can be transmitted from IDU **102**, across communication pathway **112**, to ODU **104**, and subsequently to antenna **116** where communication over a wireless link can then be initiated. Also, microwave backhaul system **100** can be implemented such that data received by antenna **116** can be transmitted from ODU **104** over communication pathway **112** to IDU **102**.

In one embodiment, ODU **104** can correct errors associated with a signal received over a wireless link via antenna **116**. Microwave backhaul system **100** can also be configured to support adaptive coding and modulation (ACM), which provides high reliability of microwave backhaul system **100** even in extreme weather, such as wind, rain, hail, or other interfering environmental conditions. For example, ACM can adapt coding and modulation rates to changing envi-

ronmental conditions to thereby increase throughput over a link and make efficient use of the existing spectrum. Thus, ACM enables the ODU to hitlessly manage the transitions when adjusting the number of transmission/receipt channels based on the changes in the communication channel

FIGS. **2**A and **2**B illustrate high-level block diagrams of an example IDU and ODU, respectively, for use within a microwave backhaul system according to an exemplary embodiment. IDU **202** and ODU **204** are coupled together via communication pathway **212**. IDU **202** can represent an exemplary embodiment of IDU **102** of FIG. **1**, and ODU **204** can represent an exemplary embodiment of ODU **104** of FIG. **1**.

IDU **202** includes a power supply unit (PSU) **206**, a CPU **208**, a modem assembly **210**, a digital-to-analog converter/analog-to-digital converter (DAC/ADC) block **216**, a modulation block **218**, and an intermediate frequency (IF) module **220**. In some embodiments, IDU **202** can also include an N-Plexer **222**. CPU **208** is configured to carry out instructions to perform arithmetical, logical, and/or input/output (I/O) operations of one or more of the aforementioned elements contained within IDU **202**. In an embodiment, CPU **208** can control operation of modulation block **218** and N-Plexer **222**.

Modem assembly **210** is configured to perform modulation and demodulation of data that is to be transmitted between IDU **202** and ODU **204**. In some embodiments, modem assembly **210** can function substantially similar to a baseband modem. Further, modem assembly **210** can be configured to cancel out noise associated with IDU **202** or communication pathway **212**. DAC/ADC block **216** can be configured to transmit and/or receive data from modem assembly **210**. DAC/ADC block **216** is also configured to perform digital-to-analog and/or analog-to-digital conversions of data such that the data is suitable for transmission over communication pathway **212**.

Modulation block **218** can also be configured to perform various modulation and/or demodulation techniques. In an embodiment, modulation block **218** can be configured to perform amplitude-shift keying. For example, modulation block **218** can be configured to perform amplitude-shift keying by utilizing a finite number of amplitudes, where each amplitude is assigned a unique pattern of binary digits. Each pattern can then be configured to form the specific symbol that is represented by the particular amplitude. Additionally, when modulation block **218** is configured to perform demodulation, modulation block **218** determines the amplitude of the received signal and maps it back to the symbol it represents, thus recovering the original data.

IF module **220** can be configured to transmit and/or receive data from DAC/ADC block **216**. IF module **220** is also configured to perform a frequency conversion of the received data such that data is suitable for transmission over communication pathway **212**. For example, IF module **220** can be configured to convert data from a baseband frequency to an IF.

N-Plexer **222** can be configured to permit N-directional communication over communication pathway **212**. In particular, N-Plexer **222** is configured to isolate IDU **202** from ODU **204**, while permitting them to share a common antenna. N-Plexer **222** is also configured to receive a control signal (e.g. a Telemetry ASK signal) output from modulation block **218**, and to receive an IF signal output from IF module **220**. Additionally, N-Plexer **222** can be configured to convert and/or combine each of these inputs to form data. N-Plexer **222** is also configured to transmit and/or receive data, over communication pathway **212**, between IDU **202** and ODU **204**. In an embodiment, N-Plexer **222** can function substantially as an analog duplexer (multiplexer/demultiplexer). In one embodiment, communication pathway **212** can be embodied as one or more IF cables that can facilitate quadruple channel communication with one or more IDUs.

In an exemplary embodiment, DAC/ADC block **216**, modulation block **218**, IF module **220** and N-Plexer **222** can be replaced by Digital N-Plexer **226**. In particular, Digital N-Plexer **226** can be configured to multiplex/demultiplex the required signal in the digital domain, rather than in the analog domain. Subsequently, Digital N-Plexer **226** can allow communication pathway **212** to be implemented as either a digital pathway or an analog pathway. Using Digital N-Plexer **226** allows for a simpler implementation of IDU **202**. For example, when implementing IDU **202** having Digital N-Plexer **226**, no analog functionality would be required, and instead only a single digital chip substrate would be needed. As a result, the cost of implementing IDU **202** can be decreased. Additionally, using a Digital N-Plexer **226** can provide an improved yield, shorter production testing, lower assembly cost, lower peripheral component count, and can support greater distances between IDU **202** and ODU **204**, to provide some examples.

As illustrated in FIG. **2**B, ODU **204** can also include an N-Plexer **228**, which can be implemented in several different manners. For example, N-Plexer **228** can be an analog N-Plexer, a digital N-Plexer, or a split function N-Plexer (e.g., where N-Plexer **228** is partially analog and partially digital). When N-Plexer **228** represents a digital N-Plexer, N-Plexer **228** can function in a substantially similar manner as Digital N-Plexer **226**. In particular, N-Plexer **228** can be configured to multiplex/demultiplex signals in the digital domain. N-Plexer **228** also allows for a simpler implementation of ODU **204** because no analog functionality would be required, and instead only a single digital chip substrate would need to be implemented within ODU **204**. Therefore, the cost of implementing ODU **204** can also be decreased. Similar to Digital N-Plexer **226**, implementing N-Plexer **228** within ODU **204** can provide an improved yield, shorter production testing, lower assembly cost, lower peripheral component count, and can support greater distances between IDU **202** and ODU **204**, to provide some examples.

In an embodiment, IDU **202** and ODU **204** can be configured to perform an N-Plexer elimination technique. In particular, the functionality directed towards filtering RX, after being received over communication pathway **212**, and TX, before being transmitted over communication pathway **212**, can be removed from N-Plexers **226** and **228**. Instead, this functionality can be implemented within the digital chip substrate (e.g., integrated circuit) that comprises IDU **202** and the digital chip substrate (e.g., integrated circuit) that comprises ODU **204**. IDU **202** and ODU **204** can then filter the required signals through any combination of an analog filtering process, a signal sampling process and/or a digital filtering process.

ODU **204** can also include CPU **230**, ADC/DAC blocks **232** and **236**, digital signal processor (DSP) **248**, and RF module **234**. CPU **230** can be configured to function in a substantially similar manner as CPU **208**. In particular, CPU **230** can be configured to carry out instructions to perform arithmetical, logical, and/or I/O operations of one or more of the elements contained within ODU **204**. In an embodiment, CPU **208** can control operation of N-Plexer **228**. ADC/DAC block **232** can be configured to transmit and/or receive data from N-Plexer **228**. ADC/DAC blocks **232** and **236** are also configured to perform analog-to-digital and/or digital-to-analog conversions of data such that data can be properly

transmitted and/or received over communication pathway **212**. Further, DSP **248** can be configured to perform mathematical manipulation techniques on data, such that data may be modified or improved according to a desired processing method. For example, DSP **248** can be configured to measure, filter, or compress data prior to being output to ADC/DAC block **236**, such that error detection and/or error correction can be performed on the data. In an embodiment, after the data is received, over communication pathway **212**, at ODU **204**, the data traverses through N-Plexer **228**, to ADC/DAC block **232**, to DSP **248**, to ADC/DAC block **236**, to RF module **234** and to antenna **244** before being transmitted across wireless link **246**. Similarly, after data is received over wireless link **246**, at ODU **204**, data traverses from antenna **244** to RF module **234**, to ADC/DAC block **236**, to DSP **248**, to ADC/DAC block **232**, and to N-Plexer **228** before being transmitted over communication pathway **212**. As will be described in greater detail below, DSP **248** can also be configured to remove the effect of interference signals from one or more interfering sources that are present in the received signals output by antenna **244**.

RF module **234** can be configured to transmit and/or receive data from ADC/DAC block **236**. RF module **234** can also be configured to perform a frequency conversion of data such that data can be properly received over communication pathway **212**. For example, when data is received at RF module **234**, data can have a frequency residing in the IF range. Therefore, RF module **234** can up-convert data from an IF to a RF such that data can then be transmitted over wireless link **246**. RF module **234** can also be configured to down-convert a signal received over the wireless link from a RF to an IF such that the received signal can be transmitted over communication pathway **212** to IDU **202**.

The deployment process of backhaul links by operators is typically governed by the state regulator, often obligating the operators to acquire several frequency bands to guarantee interference-free operation of the multiple backhaul links. In the present disclosure, it is recognized that reducing the associated cost of holding multiple frequency bands to cover a certain region is desirable.

Typically, a straight-line, multi-hop backhaul link includes no more than 2-3 hops, before the straight line breaks. FIG. **3** illustrates an example backhaul scenario of a straight-line, multi-hop backhaul link. As illustrated, such a link includes three hops, wherein each of the hops uses a different frequency band f_{c1}, f_{c2}, f_{c3} to assure no inter-hop interference.

In the present disclosure, a solution is presented that enables reuse of the same single channel over and over in a plurality of backhaul links in the network. Frequency reuse is enabled through the cancellation of interfering signals generated by interference sources. In one embodiment, a conventional dish antenna is complemented with one or more additional auxiliary antennas (e.g., isotropic). Here, the one or more additional auxiliary antennas enable cancellation of interfering signals whose direction of arrival (DOA) is off the dish antenna's bore-sight.

The dish antenna output signal includes the highly-amplified desired signal summed with an undesired interference signal arriving off bore-sight but with a lower gain (e.g., −35 dBc) compared to the desired signal. This is due to the side-lobes gain of the dish antenna. In the example, this results with a limiting SNR of 35 dB. To avoid this interference in microwave backhaul links, regulators typically obligate use of different frequency bands, thereby driving up costs for the operators.

An auxiliary omni-directional antenna output signal includes an equal gain summation of the desired signal and the interference signal. In the present disclosure, it is recognized that by pre-adjusting the gain of this signal followed by a subtraction from the dish antenna's output, the interference signal is cancelled with a small gain penalty in the desired signal. In general, output signals are down-converted to baseband such that a digital circuit is then able to remove the interfering signals and extract only the desired signal.

To illustrate this concept, reference is made to the example multi-hop backhaul link illustrated in FIG. **4**. As illustrated, the interfering signal's DOA into Hop 2's receive antenna is at an angle α off the bore-sight. The dish antenna has a radiation pattern denoted as $U_d(\theta)$ and the isotropic antenna radiation pattern is denoted by $U_i(\theta)$. By definition, the omni-directional nature of the isotropic antenna dictates that the isotropic antenna radiation pattern is a constant for all angles (at least in 2D). The dish antenna, on the other hand, has a radiation pattern that is angle-selective. In other words, there is high gain in the narrow few degrees of the bore-sight beam, with significant but not satisfactory side-lobes response. FIG. **5** illustrates an example performance of a directional dish antenna.

To illustrate an interference cancellation mechanism that enables frequency reuse, reference is now made to FIG. **6**, which illustrates an example backhaul link with two interferers. In this example, the antenna configuration again includes a parabolic dish antenna complemented by one isotropic antenna. The output of the parabolic dish antenna is y_d, while the output of the isotropic antenna is y_i. Here, it should be noted that more than one isotropic antenna can be used in different embodiments to address one or more interference sources that can exist in a given installation scenario.

In the example of FIG. **6**, the received signals at the parabolic dish antenna and the isotropic antenna can be described as follows:

$$\underline{y} = \begin{bmatrix} y_d \\ y_i \end{bmatrix} = \begin{bmatrix} G_d(\alpha_1)A & G_d(\alpha_2)A & G_d(0) \\ G_i(\alpha_1)A & G_i(\alpha_2)A & G_i(0) \end{bmatrix} \begin{bmatrix} x_{11} \\ x_{12} \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \triangleq H \cdot \underline{x} + \underline{n}$$

where x_{11}, x_{12}, and x_2 are the independent transmitted signals over Hop 11, Hop 12, and Hop 2, respectively, n_1, n_2 are the independent additive white Gaussian noise (AWGN) at the respective antennas, and His the channel describing this system. 20 $\log_{10}$A [dB] is the interferers power above the desired signal (e.g., 20 $\log_{10}$A=30 dBc), i.e., both interferers transmit power is the same.

$$E|n_{1,2}|^2 = \sigma^2,\ E|x_{1,2}|^2 = 1,\ SNR_{planned} = \frac{1 \cdot (G_d(0))^2}{\sigma^2}$$

is the planned link SNR in the desired link (e.g., 40 dB) if no interferers were present (i.e., no frequency reuse). 20 $\log_{10}G_d(0)$ [dBi] is the dish antenna gain at bore-sight (e.g., 43.6 dBi for a typical microwave antenna). 20 $\log_{10}G_d(\alpha)$ [dBi] is the dish antenna gain at DOA α. 20 $\log_{10}G_i(0)$ [dBi] is the isotropic antenna gain at bore-sight. 20 $\log_{10}G_i(\alpha_{1,2})$ [dBi] is the isotropic antenna gain at DOA $\alpha_{1,2}$. If the interferer transmitters (x_{11}, x_{12}) are located at the same height of the desired signal transmitter (x_2) then the latter

two terms ($20\log_{10}G_i(0)$ and $20\log_{10}G_i(\alpha_{1,2})$) are of equal gain value, since the omni-directional antenna has an equal gain over horizontal rotation.

The appropriate Linear Minimum Mean Square Equalizer (LMMSE) solution that can be determined by the signal processing module is then:

$$\hat{\underline{x}} = H'(HH' + \sigma^2 I)' \cdot \underline{y} \triangleq C \cdot \underline{y} = C \cdot (H\underline{x} + \underline{n}) = CH\underline{x} + C\underline{n}$$

In one example, the signal processing module is embodied as DSP **248**. The LMMSE solution can be described as a fixed solution as it can be assumed that the channel H is known. In another embodiment, the signal processing module H is unknown and can be estimated. For example, a Least Mean Square (LMS) solution can provide an adaptive way of implementing LMMSE by estimating H. Here, the LMS solution would attempt to minimize error over time by updating and improving the estimation of H, and hence C. Note that in other embodiments, other solutions can be based on Minimum Mean Square Equalizer or Maximum Likelihood.

Further note that out of the two forms of the LMMSE solutions (both are identical as long as $\sigma^2 \neq 0$):

$$H^+(HH^+ + \sigma^2 I)^{-1} \text{ and } (H^+H + \sigma^2 I)^{-1}H^+$$

In one embodiment, the chosen one is the former one, which achieves better numerical accuracy for under-determinant systems (and especially for high planned SNR), that is too few measurements in conjunction with too much signals—as is the case here. And specifically for the desired signal:

$$\hat{x}_2 = \overbrace{(CH)_{(3,3)}x_2}^{signal} + \overbrace{(CH)_{(3,1)}x_{11} + (CH)_{(3,2)}x_{12}}^{res.\ interferences} + \overbrace{(C)_{(3,1)}n_1 + (C)_{(3,2)}n_2}^{noise}$$

Therefore the resultant SINR is:

$$SINR_{dish+isotropic} = \frac{|(CH)_{(3,3)}|^2 \cdot 1}{|(CH)_{(3,1)}|^2 \cdot 1 + |(CH)_{(3,2)}|^2 \cdot 1 + \sigma^2[|(C)_{(3,1)}|^2 + |(C)_{(3,2)}|^2]}$$

If the isotropic (omni-directional) antenna is not used then only the dish antenna's output is available:

$$y_d = [\, G_d(\alpha_1) \cdot A \quad G_d(\alpha_2) \cdot A \quad G_d(0) \,] \begin{bmatrix} x_{11} \\ x_{12} \\ x_2 \end{bmatrix} + n_1 =$$

$$G_d(0)x_2 + G_d(\alpha_1) \cdot Ax_{11} + G_d(\alpha_2) \cdot Ax_{12} + n_1$$

The LMMSE solution for this case, C, is a multiplying scalar and as such it preserves the SINR at its input (output SINR equals to input SINR).

$$SINR_{dish.only} = \frac{C^2}{C^2} \frac{(G_d(0))^2}{(G_d(\alpha_1) \cdot A)^2 + (G_d(\alpha_2) \cdot A)^2 + \sigma^2} =$$

-continued

$$\frac{(G_d(0))^2}{(G_d(\alpha_1) \cdot A)^2 + (G_d(\alpha_2) \cdot A)^2 + \sigma^2}$$

Again the SNR gain will actually be a negative number (i.e., it will be a penalty) is:

$$SNRGain_{dish+isotropic} = \frac{SNR_{dish+isotropic}}{SNR_{planned}}$$

$$SNRGain_{dish.only} = \frac{SINR_{dish+isotropic}}{SNR_{planned}}$$

The performance in the example presence of two interferers can be depicted as shown in FIG. **7**. As illustrated in the example of FIG. **7** only when both interferers are roughly at the same DOA of X (e.g., ~45) or alternatively one interferer is at X° and the other one is at mirror angle (−X°) then the performance loss, in the case of isotropic assisted cancellation, can be limited to less than 3 dB and it could even reach 0.3 dB. Therefore the cancellation coverage is significantly narrowed down to ±45+(−13.8°) such that loss is less than 3 dB.

The output of the equalizer, specifically for the desired signal x_2 will have a significantly improved SNR compared to the case where no auxiliary antenna(s) were used and the dish antenna operated on its own. It can be shown that the overall system of the dish antenna plus one or more auxiliary antennas plus digital baseband processing is equivalent to a significantly (more than 30 dB lower side-lobes) improved (much narrower) single dish antenna response as shown in FIG. **8**.

The implication of this solution is that the link-planned SNR can be preserved even in the presence of co-channel strong interferers. This enables operators to significantly reduce spectrum holding yearly fees by sufficing with holding only a single frequency band. It also eases the network frequency planning because such a system is significantly robust of interferers. The number of auxiliary antennas and their type (directional, omni-directional, etc.) is a design parameter and can be traded off at the expense of performance preservation in the main link.

Having described an equalizer system that complements a parabolic dish antenna with one or more auxiliary antennas, reference is now made to the flowchart of FIG. **9**, which illustrates an example process. As illustrated, the process can begin at step **902** where a signal processing module receives first signals based on an output of a parabolic dish antenna. Next, at step **904**, the signal processing module receives second signals based on output(s) from one or more auxiliary antennas (e.g., isotropic).

The first signals include a desired signal along with interference generated by one or more interference sources transmitting in the same frequency band as the desired source. In one example, the one or more interference signals are received by the parabolic dish antenna at a DOA that is off the dish antenna's bore-sight and at a lower gain. In contrast, the one or more auxiliary antennas output signal can include an equal gain summation of the desired signal and the interference signal.

At step **906**, the signal processing module can then be configured to remove interference from one or more interfering sources n the first signals using the second signals. The cancellation of the interference signals can be performed with a small gain penalty in the desired signal from

the desired source. As a result, the relative interference of the one or more interference sources is reduced, thereby enabling greater opportunities for frequency reuse.

A solution has been described based on the example of two interferers and one auxiliary antenna. This example is not intended to be limiting to the scope of the present disclosure. The solution outlined above can be generalized to extend to different numbers of interferers and a different number of auxiliary antennas as would be appreciated.

Another embodiment of the present disclosure can provide a machine and/or computer readable storage and/or medium, having stored thereon, a machine code and/or a computer program having at least one code section executable by a machine and/or a computer, thereby causing the machine and/or computer to perform the steps as described herein.

Those of skill in the relevant art would appreciate that the various illustrative blocks, modules, elements, components, and methods described herein may be implemented as electronic hardware, computer software, or combinations of both. To illustrate this interchangeability of hardware and software, various illustrative blocks, modules, elements, components, methods, and algorithms have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Those of skill in the relevant art can implement the described functionality in varying ways for each particular application. Various components and blocks may be arranged differently (e.g., arranged in a different order, or partitioned in a different way) all without departing from the scope of the subject technology.

These and other aspects of the present disclosure will become apparent to those skilled in the relevant art by a review of the preceding detailed disclosure. Although a number of salient features of the present disclosure have been described above, the principles in the present disclosure are capable of other embodiments and of being practiced and carried out in various ways that would be apparent to one of skill in the relevant art after reading the present disclosure, therefore the above disclosure should not be considered to be exclusive of these other embodiments. Also, it is to be understood that the phraseology and terminology employed herein are for the purposes of description and should not be regarded as limiting.

What is claimed is:

1. A microwave receiver system, comprising:

a parabolic dish antenna that is configured to receive microwave signals transmitted via a plurality of backhaul links, wherein the plurality of backhaul links comprises at least a first link and a second link, wherein a first node is configured to transmit a first signal to a second node via the first link using a first frequency band, and a second node is configured to transmit a desired signal to the parabolic dish antenna via the second link using the first frequency band, wherein the first node further comprises an interference source by transmitting an interference signal in the first frequency band comprising at least a portion of the first signal directly to the parabolic dish antenna, the parabolic dish antenna further configured to generate a dish antenna output according to the desired signal and the interference signal received by the parabolic dish antenna;

one or more auxiliary antennas that are configured to receive microwave signals comprising a version of the desired signal from the second node and a version of the interference signal directly from the first node, and generate one or more auxiliary antenna outputs according to the version of the desired signal and the version of the interference signal received by the one or more auxiliary antennas; and

a signal processing module that is configured to receive first signals based on the dish antenna output and second signals based on the one or more auxiliary antenna outputs, the processing module further configured to use the one or more auxiliary antenna outputs to remove interference from the interference source that are present in the first signals based on the dish antenna output.

2. The microwave receiver system of claim **1**, further comprising an RF module that down-converts the dish antenna output.

3. The microwave receiver system of claim **1**, wherein the one or more auxiliary antennas are isotropic antennas.

4. The microwave receiver system of claim **1**, wherein the one or more auxiliary antennas comprise a single auxiliary antenna.

5. The microwave receiver system of claim **1**, wherein the one or more auxiliary antennas comprise a plurality of auxiliary antennas.

6. The microwave receiver system of claim **1**, wherein the signal processing module uses a Linear Minimum Mean Square Equalizer technique to remove the interference signal.

7. The microwave receiver system of claim **1**, wherein the signal processing module uses a Minimum Mean Square Equalizer technique to remove the interference signal.

8. The microwave receiver system of claim **1**, wherein the signal processing module uses a Maximum Likelihood technique to remove the interference signal.

9. A method, comprising:

generating a dish antenna output from a parabolic dish antenna that is configured to receive microwave signals transmitted via a plurality of backhaul links, wherein the plurality of backhaul links comprises at least a first link and a second link, wherein a first node is configured to transmit a first signal to a second node via the first link using a first frequency band, and a second node is configured to transmit a desired signal to the parabolic dish antenna via the second link using the first frequency band, wherein the first node further comprises an interference source by transmitting an interference signal in the first frequency band comprising at least a portion of the first signal directly to the parabolic dish antenna, the parabolic dish antenna further configured to generate the dish antenna output according to the desired signal and the interference signal received by the parabolic dish antenna;

generating one or more auxiliary antenna outputs from one or more auxiliary antennas that are configured to receive microwave signals, the microwave signals comprising a version of the desired signal from the second node and a version of the interference signal directly from the first node, the one or more auxiliary antenna outputs generated according to the version of the desired signal and the version of the interference signal received by the one or more auxiliary antennas; and

removing, using a signal processing module configured to receive first signals based on the dish antenna output and second signals based on the one or more auxiliary antenna outputs, interference from the interference

source that are present in the first signals, wherein the one or more interference sources transmit in the same frequency band as the desired source.

10. The method of claim **9**, further comprising down-converting the dish antenna output using an RF module.

11. The method of claim **9**, wherein the one or more auxiliary antennas are isotropic antennas.

12. The method of claim **9**, wherein the one or more auxiliary antennas comprise a single auxiliary antenna.

13. The method of claim **9**, wherein the one or more auxiliary antennas comprise a plurality of auxiliary antennas.

14. The method of claim **9**, wherein the removing comprises removing using a Linear Minimum Mean Square Equalizer technique.

15. The method of claim **9**, wherein the removing comprises removing using a Minimum Mean Square Equalizer technique to remove the interference signal.

16. The method of claim **9**, wherein the removing comprises removing using a Maximum Likelihood technique to remove the interference signal.

17. A method, comprising:

receiving, by a signal processing module, first signals based on an output of a parabolic dish antenna that is configured to receive microwave signals from a desired source, the first signals transmitted via a plurality of backhaul links, wherein the plurality of backhaul links comprises at least a first link and a second link, wherein a first node is configured to transmit a first signal to a second node via the first link using a first frequency band, and a second node is configured to transmit a desired signal to the parabolic dish antenna via the second link using the first frequency band, wherein the first node further comprises an interference source by transmitting an interference signal in the first frequency band comprising at least a portion of the first signal directly to the parabolic dish antenna, the parabolic dish antenna further configured to generate the dish antenna output according to the desired signal and the interference signal received by the parabolic dish antenna;

receiving, by the signal processing module, second signals based on an output of one or more auxiliary antennas, the second signals comprising a version of the desired signal from the second node and a version of the interference signal directly from the first node, the output of the one or more auxiliary antenna generated according to the version of the desired signal and the version of the interference signal received by the one or more auxiliary antennas; and

removing, using the signal processing module, configured to receive first signals based on the dish antenna output and second signals based on the one or more auxiliary antenna outputs, interference from the interference source that are present in the first signals, wherein the one or more interference sources transmit in the same frequency band as the desired source.

18. The method of claim **17**, wherein the one or more auxiliary antennas are isotropic antennas.

19. The method of claim **17**, wherein the one or more auxiliary antennas comprise a single auxiliary antenna.

20. The method of claim **17**, wherein the one or more auxiliary antennas comprise a plurality of auxiliary antennas.

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